PB85-207520

Measurement of Sulfur and Carbon Species Emissions from Oil-Fired Commercial and Institutional Boilers

Battelle Columbus Labs., OH

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Apr 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-207520

EPA/600/3-85/030
April 1985

MEASUREMENT OF SULFUR AND CARBON SPECIES EMISSIONS FROM OIL-FIRED COMMERCIAL AND INSTITUTIONAL BOILERS

by

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RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/3-85/030		PB85 207520/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
MEASUREMENT OF SULFUR AND CARBON SPECIES EMISSIONS FROM OIL-FIRED COMMERCIAL AND INSTITUTIONAL BOILERS	April 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
S.E. Miller	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	CDTA1D-01/1608 (FY-84)
	11. CONTRACT/GRANT NO.
	68-02-3487
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Atmospheric Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711	Final
	14. SPONSORING AGENCY CODE
	EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This research program was to provide source emission data for urban particulate models. The objectives were twofold: to determine emission factors for primary sulfate and carbon from a variety of commercial and industrial heating units burning fuel oil, and to evaluate and compare the performance of the miniature acid condensation system (MACS) and the acid condensation system (ACS) methods for determining free sulfuric acid.

A total of five boilers were monitored in this study. Two of the units tested were utility boilers. The remaining three units were small process steam or heating boilers ranging in size from 23,500 to 50,000 lb/hr.

The results of this study provide evidence that the MACS system, although subject to certain critical sampling parameters, can serve as a primary sulfate characterization method for combustion source measurements. Analytical data on carbon and elemental composition are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	55
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract 68-02-3487 to Battelle's Columbus Laboratories. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document.

ABSTRACT

This research program was initiated in support of a program to provide source emission data for urban particulate models. The objectives of the study were twofold: to determine emission factors for primary sulfate and carbon from a variety of commercial and industrial heating units burning fuel oil, and to evaluate and compare the performance of the miniature acid condensation system (MACS) and the acid condensation system (ACS) methods for determining free sulfuric acid.

A total of five boilers were monitored in this study. Two of the units tested were utility boilers. The remaining three units were small process steam or heating boilers ranging in size from 23,500 to 50,000 lb/hr.

Particulate samples for the determination of mass loading, sulfate, carbon and trace element analysis, were collected at each boiler using a standard Method 5 sampling train. SO_2 and H_2SO_4 emission data were obtained at each boiler by two methods--Acid Condensation System (ACS) and Miniature Acid Condensation System (MACS). For comparison purposes, both methods were run concurrently from the same sampling port. The tests were conducted as single point samples with average ΔP values determined from Method 5 particulate runs. Fuel oil grab samples were acquired daily from each site.

The results of this study provide evidence that the MACS system, although subject to certain critical sampling parameters, can serve as a primary sulfate characterization method for combustion source measurements. Analytical data on carbon and elemental composition are presented, but conclusions are left to the reader.

This report was submitted in fulfillment of Contract No. 68-02-3487 (WA's 6 and 12) by Battelle's Columbus Laboratories under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period May 1, 1981 through March 10, 1983. Work was completed as of December 23, 1982.

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ACKNOWLEDGMENT

The authors wish to acknowledge the enthusiastic cooperation of those companies and individuals who made available their boilers and plant facilities for this research study.

Acknowledgement is also made to J. J. Huntzicker, Chairman of the Department of Environmental Science, Oregon Graduate Center, for carbon analyses, and to Robert Kellogg, Northrup Services, Inc., Research Triangle Park, N.C., for particulate and fuel oil analyses.

Special acknowledgement is due J. L. Cheney, EPA Environmental Science Research Laboratory, for furnishing and assisting in the operation of the MACS sampling trains.

SECTION 1

INTRODUCTION

During the past decade, receptor oriented models have evolved rapidly and are now recognized as distinct disciplines. The models have been widely accepted and are currently one of the primary tools employed by control agencies to estimate the impact of sources at receptor sites. As is often the case, the rapid evolvement of models for particulate matter has resulted in certain inadequacies. Although large volumes of data have been accumulated on the chemical and physical characteristics of particulate matter, little is known about its sources and subsequent contributions to specific receptor sites. The source impact on ambient loadings at these sites is recognized as an approximation at best. This approximation is due largely to the many variables (primarily meterological) which are random in nature, change with space and time, and may combine with other variables in a nonlinear manner.

If modeling of particulate emissions is to acquire its anticipated prominence in air particulate control programs, additional research is needed to more adequately define the boundaries of the models and to rectify some of the inherent weaknesses such as those described above. Additional work is also needed to improve the sampling and analytical techniques used in assessing the effect of individual sources. Due to the potential adverse health and environmental effects of sulfates and carbon particles, products of combustion from coal- and oil-fired boilers have been given top priority. In conducting sulfate emission measurements of combustion sources, EPA has evaluated several procedures for determining sulfuric acid. A development originating from this work is the miniature acid condensation system (MACS) which shows promise as a reliable, simplified method for determining sulfuric acid. However, additional evaluation of the MACS is needed to demonstrate the efficiency of the method.

The purposes of this study were twofold: to provide improved techniques for urban particulate models by determining emission factors for primary sulfate and carbon from a variety of commercial and institutional heating units burning fuel oil, and to evaluate and compare the performance of the MACS and the ACS (acid condensation system) methods for differentiating free sulfuric acid and sulfate salts.

The data summarized in this report are the results of two individual work assignments (6 and 12) emanating from EPA Contract No. 68-02-3487. The field portion of WA-6 was conducted in Philadelphia, PA, during the period March 22 to April 6, 1982. WA-12 was conducted in Philadelphia, PA, during the period August 4 to August 14, 1982. The time frame for the latter study coincided with EPA's Philadelphia Aerosol Field Study.

SECTION 2

CONCLUSIONS

The results of this study provide evidence that the Miniature Acid Condensation System (MACS) can serve as a primary sulfate characterization method for combustion source measurements. Within experimental error, the glass-wool plug will collect H_2SO_4 as well as the Goksoyr-Ross type condenser. The study also shows, as was evident in the winter study, that both methods (MACS and ACS) must be used with caution. Both methods of evaluation are subject to certain critical sampling parameters (filtration temperature and sampling flow rate) which, if varied for any reason, will result in incomparable and erroneous data.

The average primary sulfate emission (H_2SO_4 + SO_4) for the three heating boilers was 3.0391 g/gal of fuel oil with a range of 1.179 to 6.033 g/gal. The two utility boilers averaged 1.5329 g/gal with a range of 1.497 to 1.724 g/gal.

Carbon emissions, in terms of mass of carbon per gallon of fuel oil burned, for the three heating boilers averaged 0.1925 g/gal with a spread of 0.01 to 0.63 g/gal. The average total carbon emissions from the two utility boilers were 1.8733 g/gal with a spread of 0.78 to 4.13 g/gal.

SECTION 3

OBJECTIVES

This study was requested by EPA's Office of Air Quality Planning and Standards (OAQPS) in support of a program to provide improved techniques for urban particulate models. The objectives of the study were twofold: to determine emission factors for primary sulfate and carbon from a variety of commercial and institutional heating units burning fuel oil, and to evaluate and compare the performance of the miniature acid condensation system (MACS) and the acid condensation system (ACS) methods for determining free sulfuric acid. The MACS is a prototype system developed by EPA[1]. Two complete systems were made available to Battelle to conduct this study.

Principal activities within the scope of the work assignments included the following:

1. Selection of commercial or industrial oil-fired boilers in the Philadelphia area for particulate emission characterization;

2. Determination of sulfate content and carbon species/content of particulate emissions, SO_2 and H_2SO_4 emissions, and all ancillary measurements of velocity, moisture, and molecular weight required for the determination of emission factors;

3. Acquisition of H_2SO_4 and SO_2 measurement at each site employing the MACS and ACS methods to evaluate the MACS method;

4. Obtain daily fuel samples and hourly firing rate data at each site followed by analysis of fuel samples for total sulfur and trace element control;

5. Preparation of a quality assurance project plan based on QAMS Document 005/80; and

6. Submission of a final report which will include emission factors data and the evaluation of the MACS method for determination of H_2SO_4.

SECTION 4

SELECTION AND DESCRIPTION OF TEST SITES

Candidate sampling sites for this study were selected from a computerized list supplied by the Air Management Service, Department of Public Health, City of Philadelphia. The list included all types of boilers (minimum design capacity of 30 MMBtu/hr) licensed to operate in the City of Philadelphia.

Initial study plans called for the monitoring of eight oil-fired boilers, four in Task 6 and four in Task 12. However, site selection became very limited due to the early conversion (March 2, 1982) from oil to natural gas. In addition, one company had to withdraw from the program at the last minute when a cutback of personnel at their plant left them without a licensed boiler operator. Their concern was with the safety of the field crew. The adversities encountered in the selection of sampling sites resulted in fewer sites and a modification in boiler size requirements. A total of five boilers were monitored in the combined studies, three in Task 6 and two in Task 12. Two of the units tested (one from each task) were utility boilers. The remaining units were small process steam or heating boilers ranging in size from 23,500 to 50,000 lb/hr. The small boiler in Task 12 was monitored at two different loads. One of the smaller boilers in Task 6 was burning an 8 percent water-oil emulsion. This unit was tested with and without the emulsifier.

Table 1 summarizes the boilers monitored in this study as to type, size, fuel, and date of installation. A Philadelphia city ordinance prohibits the burning of fuel oil containing >0.5 percent sulfur.

Boiler operational data, i.e., load, fuel consumption and Fyrite measurements are presented in Appendix A.

TABLE 1. BOILER SUMMARY

Boiler Designation	Type	Rating, lb/hr	Fuel	Installation Date	Economizer
Task 6					
GIR	Heating	25,000	No. 4 Oil	1975	
PE	Utility	260,000	No. 6 Oil	1969	X
MI	Heating	23,500	No. 6 Oil	1965	
Task 12					
PES	Utility	600,000	No. 6 Oil	1973	X
SBS	Heating	50,000	No. 6 Oil	1946	

SECTION 5

SAMPLING PROCEDURES

The sampling program for this study was designed to make maximum use of existing stream access sites. In those cases where sampling ports were nonexistent, four-inch ports were welded into place at the most desirable location. While care must always be exercised to ensure that the samples are not biased, the commonly applied concepts of multiple point, isokinetic, or flow proportional sampling were not rigidly adhered to in this study.

PARTICULATE COLLECTION

Particulate samples for the determination of mass loading, sulfate, carbon, and trace element analysis, were collected at each boiler using a standard Method 5 sampling train as shown in Figure 1. The sampling site requirements specified for Method 5 in CFR Title 40, Part 60, prevent sampling in locations situated either near or in areas of flow disturbance. This requirement could not be met in all of the boilers tested in this study because of the small duct sizes and manifolding of several boilers into common stacks. Accordingly, the particulate emission tests were conducted as single point samples. This variant was done with the full knowledge and approval of the EPA Administrator. A preliminary velocity traverse of each duct was conducted with an S-type pitot. From the traverse data, an average flow velocity was calculated from the squared mean of the square roots of the measured differential pressure (ΔP) values. A sampling point corresponding to the average velocity within the traverse was selected and the ΔP at this point was monitored throughout the test period with the volume flowrate continuously adjusted to maintain an isokinetic sampling rate.

Ancillary measurements required to calculate emission factors were made according to EPA Methods 1, 2, 3, and 4.

SO_2 AND H_2SO_4 COLLECTION

SO_2 and H_2SO_4 emission data were obtained at each boiler by two methods - Acid Condensation System (ACS) and Miniature Acid Condensation System (MACS). The systems are shown in Figures 2 and 3, respectively. For comparison purposes, both methods were run concurrently from the same sampling port. The tests were conducted as single point samples with average ΔP values determined from Method 5 particulate runs.

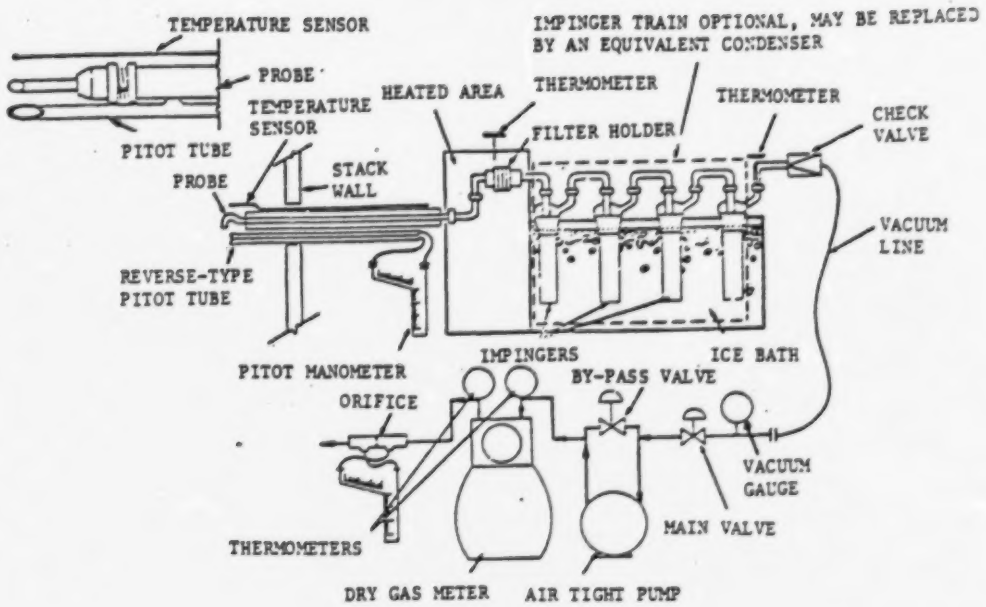

Figure 1. Particulate sampling train.

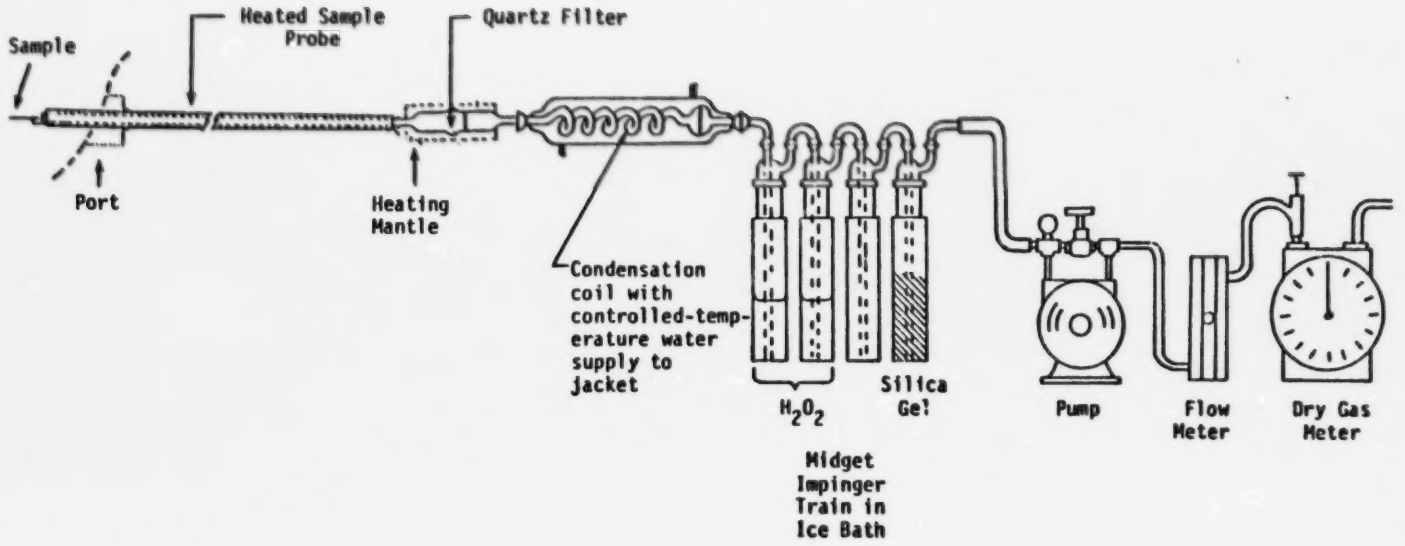

Figure 2. SO_2/H_2SO_4 sampling system (ACS)

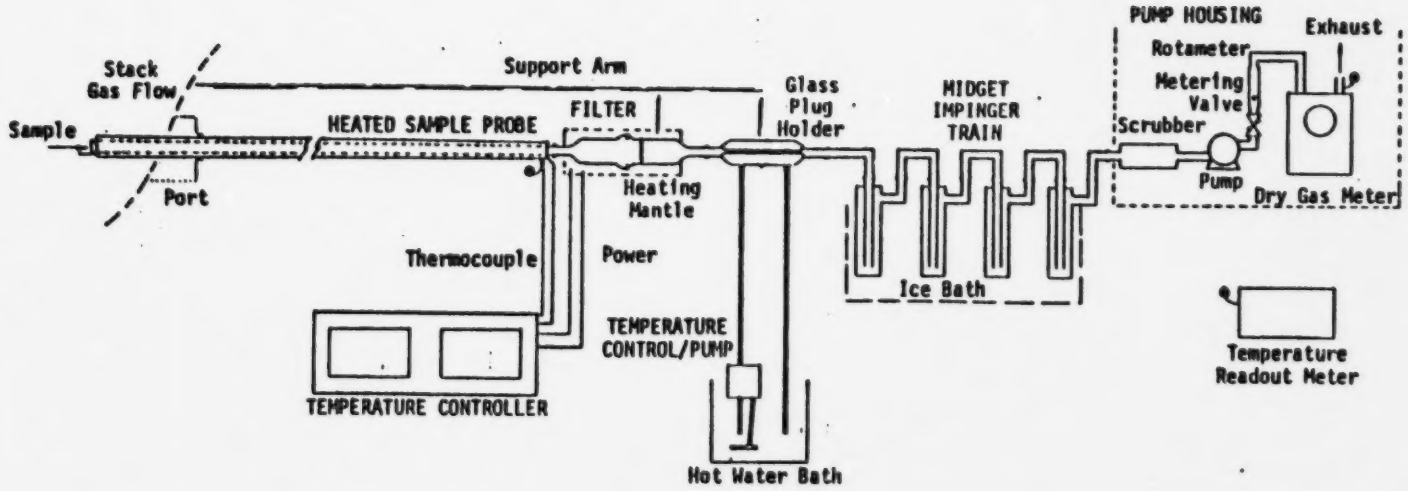

Figure 3. Miniature acid condensation sampling (MACS) system.

During the initial study (Task 6) flow problems were encountered in the MACS system. A high pressure drop was introduced into the system from the glass wool plug. With repeated use the glass wool is redistributed and collects at one end of the plug holder restricting the gas flow. The resulting high pressure drop, along with the continuously changing pressure drop, resulted in difficulties in maintaining a consistent and repeatable sampling rate. This problem was alleviated during the second half of the study (Task 12) by enlarging the bore size of the glass wool plug holder and packing the wool in a more serviceable manner.

FUEL SAMPLE COLLECTION

Fuel oil grab samples were acquired daily from each site in areas between the fuel storage tank and the boiler. The samples were stored in new glass pint bottles which had been laboratory-prepared by washing with a mild detergent, copiously rinsing in distilled water, and drying overnight at temperatures high enough to ensure combustion of any residual organic material. The bottles were filled completely to the top so that no dead air space remained and fitted with Teflon-lined screw caps.

The number and type of runs conducted at each site are summarized in Table 2. The table also includes the number of fuel oil samples obtained.

TABLE 2. NUMBER AND TYPE OF RUNS AT EACH SITE

Site	Date	Method 5	ACS[1]	MACS[2]	Fuel
Task 6					
GIR	3/23 - 3/27	5	6	7	4
PE	3/27 - 4/1	3	6	6	3
MI	4/1 - 4/6	3	6	6	3
Task 12					
PES	8/4 - 8/6	3	5	5	3
SBS	8/9 - 8/12	4	8	8	4

[1]Acid Condensation System.
[2]Microacid Condensation System.

SECTION 6

SAMPLE RECOVERY AND ANALYTICAL PROCEDURES

PARTICULATE MASS

EPA Method 5 was employed in the collection of particulate matter for the determination of mass loading, sulfate and carbon content, and trace element analysis. Mass loading was determined from the front half rinse, i.e., probe nozzle, probe, and front half of the filter holder, and the filter catch. The acetone front half rinse was evaporated to dryness at ambient temperatures and pressure, desiccated for 24 hours and weighed to a constant weight. The 76.4 mm (3.0 inch) Pallflex Tissue Quartz filters were desiccated to dryness and weighed to a constant weight of $\pm$ 0.5 mg. After sampling, the filters were weighed using the same criterion and the net particulate catch determined.

Following mass loading determinations, the filters were divided into three sections as illustrated in Figure 4. One half of each filter

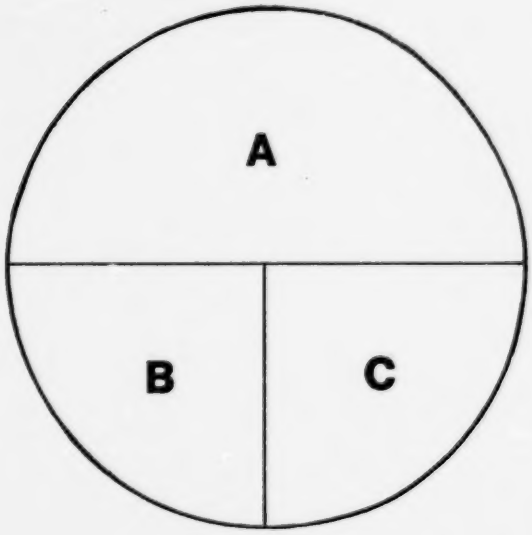

Figure 4. Filter sections.

(section A) was sent to EPA's Environmental Sciences Research Laboratory where they were analyzed for elemental composition using a Siemens Model MRS-3, wavelength dispersive, X-ray spectrometer. One quarter of each filter (section B) was sent to the Oregon Graduate Center where carbon forms, i.e., organic carbon, elemental carbon, total carbon, and $CO_3^=$, were determined by an automated thermal-optical method. Section C of the filter was analyzed for particulate sulfate by ion chromatography. This work was done at Battelle Columbus Laboratories using a Model 16 Dionex IC unit.

PRIMARY SULFATES

SO_2 and H_2SO_4 emission data were obtained by two methods, the Acid Condensation System (ACS) and the Micro-Acid Condensation System (MACS). From the functional diagrams presented in Figures 2 and 3 it can be seen that the two systems are very similar. The major difference in the two systems lies with the H_2SO_4 collector. The ACS train condenses the H_2SO_4 in a temperature controlled (60 C, 140 F) condensation coil, while the MACS train uses a temperature controlled (60 C, 140 F) glass wool plug.

Sample recovery from the two systems is identical, with three sample fractions being recovered from each system. The three sample fractions include - the front half rinse (FHR), the controlled condensation coil rinse (CCC)/glass wool plug rinse (GWP), and the impinger sections. In this study the FHR which includes the probe, particulate filter, and holder, was recovered by washing with 100 percent Isopropanol. The CCC from the ACS train and the GWP from the MACS train were both recovered with D.I. water. The impingers and their connecting U-tubes were also rinsed in D.I. water. The FHR and the CCC/GWP provide a gaseous H_2SO_4 measurement. Analysis of the impinger catch for SO_4 provides an SO_2 measurement. The analytical methods used in the analysis of the recovered sample fractions from the ACS and MACS trains are summarized in Table 3. Also included in Table 3 are summaries of the analytical methods employed in the analysis of particulate and oil samples.

TABLE 3. SAMPLE RECOVERY AND ANALYTICAL PROCEDURES

System	Sample Fraction	Rinse	Analytical Procedure
ACS	FHR[1] (H_2SO_4)	IPA, 100%	Barium Thorin Titration
ACS	CCC[2] (H_2SO_4)	D.I. H_2O	Ion Chromatography
ACS	Impingers (SO_2)	D.I. H_2O	Barium Thorin Titration
MACS	FHR (H_2SO_4)	IPA, 100%	Barium Thorin Titration
MACS	GWP[3] (H_2SO_4)	D.I. H_2O	Ion Chromatography
MACS	Impingers (SO_2)	D.I. H_2O	Barium Thorin Titration
Method 5	FHR (Mass)	Acetone	Gravimetric
Method 5	Filter (Mass)	NA	Gravimetric
Method 5	Filter (Carbon)	NA	Thermal/Optical
Method 5	Filter (SO_4)	NA	Ion Chromatography
Method 5	Filter (Elemental)	NA	X-Ray Fluorescence (Wavelength Dispersive)
Fuel	[illegible] (V)	NA	Inductively Coupled Argon Plasma
Fuel	[illegible] (S)	NA	X-Ray Fluorescence (Non-Dispersive)
Fuel	Oil (Elemental)	NA	X-Ray Fluorescence (Wavelength Dispersive)

[1]Front Half Rinse
[2]Controlled Condensation Coil
[3]Glass Wool Plug.

SECTION 7

RESULTS AND DISCUSSIONS

COMPARISON OF THE ACS AND MACS METHODS FOR MEASURING SULFURIC ACID (H_2SO_4)

The objective of this portion of the study was to compare the two methods, ACS and MACS, for measuring sulfuric acid (H_2SO_4). Simultaneous measurements were made using both measurement techniques on eighteen samples in the winter study and on thirteen samples in the summer study. The data collected during these two studies are presented in Table 4. The ppm values summarized in Table 4 were calculated from the total $SO_4^=$ values obtained from the front half rinse and the condensation coil/glass wool plug in accordance with the following equations:

$$\text{mg } SO_4^= \times \frac{98.08}{96.06} = \text{mg } H_2SO_4$$

$$\frac{\text{mg } H_2SO_4}{\text{Sample Volume, dscm}} \times \frac{24.04}{98.08} = \text{ppm} \quad .$$

The comparison of two methods which are designed to measure the same property of a chemical sample is a standard scientific and statistical problem. In general, the overall comparison of two measurement techniques involves comparison of both economic and technical criteria. For example, the cost of equipment, time required to complete a measurement, and level of skill required by the operator are economic criteria of interest. Accuracy and precision are technical criteria of interest. Of these criteria the comparison of accuracy and precision are criteria which can be addressed statistically. The following discussion is devoted to the comparison of the two measurement methods with respect to technical criteria only.

ESTABLISHMENT OF A STATISTICAL MODEL FOR THE COMPARISON OF THE TWO METHODS

Despite the apparent simplicity of the problem, the comparison of two alternative measurement techniques with respect to technical criteria is not trivial. First, the parameters which characterize a given method's accuracy and precision must be defined.

TABLE 4. SUMMARY OF H_2SO_4 DATA, ACS VERSUS MACS

Test No.	ACS, ppm	MACS, ppm
	Winter Study	
GIR - 1	5.00	2.75
GIR - 2	2.77	2.13
GIR - 3	3.39	2.55
GIR - 4	3.50	3.34
GIR - 5	5.05	2.59
GIR - 6	2.57	3.00
PE - 1	2.53	2.17
PE - 2	2.46	2.73
PE - 3	2.66	3.25
PE - 4	3.24	3.05
PE - 5	10.92*	1.99*
PE - 6	8.68	1.09
MI - 1	3.04	4.30
MI - 2	7.10	4.36
MI - 3	5.62	4.77
MI - 4	5.67	4.17
MI - 5	7.11	6.13
MI - 6	7.74	3.24
	Summer Study	
PES - 1	4.35	5.35
PES - 2	2.29	1.86
PES - 3	2.45	1.60
PES - 4	2.20	2.00
PES - 5	4.49	1.00
SBS - 1	0.83	0.23
SBS - 2	0.74	0.76
SBS - 3	0.77	0.81
SBS - 4	0.79	0.77
SBS - 5	0.84	0.74
SBS - 6	0.74	0.74
SBS - 7	0.81	0.78
SBS - 8	0.77	0.80

*Data not included in statistical analysis due to anomalous value for ACS technique.

Every method of measurement is subject to random and systematic errors. Random error is usually quantified in terms of precision, and systematic error in terms of accuracy. Method precision is a measure of method repeatability. Systematic error is the tendency of the method to consistently over or underestimate the true amount of substance being measured.

The systematic error has two components: (1) a fixed bias which is independent of the true level being measured, and (2) a proportional bias which depends upon the true level.

The appropriate statistical model which identifies these method characteristics is given by

$$X_i = \alpha + \beta C_i + \varepsilon_i \quad , \quad \varepsilon_i \sim N(0, \sigma^2) \tag{1}$$

where X_i is the observed measured value for the i^{th} sample, and C_i is the true concentration of the substance in the sample. The random error term ε_i is assumed to be normally distributed with mean zero and variance σ^2. The standard deviation $\sigma = \sqrt{\sigma^2}$ measures the precision of the method, α is the fixed bias and $\beta - 1$ measures the proportional bias. If there is no systematic error in the method, then $\alpha = 0$ and $\beta = 1$.

For a single method under study, interest would focus on the estimation of α, β, and σ. It is clear that if the true values C_i were not known, then it would be impossible to estimate these parameters.

The problem we are faced with in comparing the ACS and MACS methods is one of not knowing the true concentration levels of H_2SO_4 in the samples. Although this unknown factor complicates the problem, a comparison of the two methods can still be made. However, as will be shown below, only relative information can be obtained concerning accuracy and no information can be retrieved with regard to precision.

With respect to two methods of measurement, the statistical model given by Equation (1) can be generalized to

$$X_{1i} = \alpha_1 + \beta_1 C_i + \varepsilon_{1i} \quad , \quad \varepsilon_{1i} \sim N(0, \sigma_1^2) \tag{2}$$

and

$$X_{2i} = \alpha_2 + \beta_2 C_i + \varepsilon_{2i} \quad , \quad \varepsilon_{2i} \sim N(0, \sigma_2^2) \tag{3}$$

Equation (2) is the statistical model for Method 1 and Equation (3) is the statistical model for Method 2.

Using Equation (3) to express the unknown value C_i in terms of X_{2i}, we obtain

$$C_i = \frac{X_{2i} - \alpha_2 - \varepsilon_{2i}}{\beta_2} \tag{4}$$

Replacing C_i in Equation (2) with Equation (4), we obtain a relationship between X_{1i} and X_{2i} given by

$$X_{1i} = \alpha_1 + \beta_1 \left(\frac{X_{2i} - \alpha_2 - \varepsilon_{2i}}{\beta_2} \right) + \varepsilon_{1i}$$

$$= \left(\alpha_1 - \frac{\beta_1}{\beta_2} \alpha_2 \right) + \frac{\beta_1}{\beta_2} X_{2i} + \varepsilon_{1i} - \frac{\beta_1}{\beta_2} \varepsilon_{2i}$$

$$= \alpha^* + \beta^* X_{2i} + \varepsilon_i^* \quad . \tag{5}$$

Equation (5) is a linear regression model in the variables X_{1i} and X_{2i} with

$$\alpha^* = \alpha_1 - \frac{\beta_1}{\beta_2} \alpha_2 \ , \quad \beta^* = \frac{\beta_1}{\beta_2} \ , \text{ and } \sigma^2_{\varepsilon^*} = \sigma_1^2 + \left(\frac{\beta_1}{\beta_2} \right)^2 \sigma_2^2 \quad .$$

A regression analysis involving the observed data (X_{1i}) and (X_{2i}) will only provide estimates of α^*, β^*, and $\sigma^2_{\varepsilon^*}$. Therefore, without additional assumptions the data obtained from this study can only be used to estimate the ratio of the proportional biases, and to relate the constant bias α_1 to the constant bias α_2 by the equation $\alpha_1 = \alpha^* + \frac{\beta_1}{\beta_2} \alpha_2$. The precision σ_1^2 and α_2^2 of the two methods cannot be compared at all.

DEFINING A REFERENCE METHOD FOR COMPARATIVE PURPOSES

As was discussed earlier, if both measurement techniques, ACS and MACS, are assumed to involve error, then a direct comparison of the two methods cannot be made for accuracy and precision determinations. This is due to the fact that the true levels of H_2SO_4 being measured are unknown. One approach to circumvent this problem is to assume that one of the two methods measures the true level of H_2SO_4. In other words, we will establish one method as a reference method, and estimate the systematic and random errors in the second method relative to the first method.

Since the ACS method is the established EPA method which has been used for a number of years, it was chosen as the reference method. An ordinary linear regression analysis was performed using the MACS measurement (Y_i) as the dependent variable and the ACS measurement (X_i) as the independent variable. The statistical model is then given by

$$Y_i = \alpha + \beta X_i + \varepsilon_i \ , \quad \varepsilon_1 \sim N(0, \sigma^2) \tag{6}$$

where α is the constant bias, β the proportional bias, and σ^2 the precision of the MCS method relative to the ACS method.

The data for the MACS method are plotted versus the data for the ACS method in Figures 5 and 6. Equation (6) was fit separately to the data collected during the winter study and to the data collected from the summer study. The results are presented in Table 5.

Figure 5 indicates that there is substantial variability in the MACS measurements relative to the ACS measurements. In addition, the slope of 0.41 for the winter study indicates that relative to the ACS method the MACS method produced lower measurements. The variability between the two systems and the lower readings of the MACS system were probably caused by the glass wool plug. With repeated use the glass wool is redistributed and collects at one end of the holder restricting the gas flow and resulting in a high pressure drop across the system. This problem was alleviated prior to the summer study.

Figure 6 identifies an anomalous value for the summer study data. If this value is excluded, then there appears to be good agreement between the two measurement techniques for the summer data. The intercept of -0.30 and the slope of 1.14 indicate little constant or proportional bias in the MACs method relative to the ACS method. Also the precision of the MACs method relative to the ACS method is better for the summer data than for the winter date.

SO_2 DATA SUMMARY

Sulfate found in the peroxide impingers of the ACS and MACS trains is summarized in Table 6 for the winter study and Table 7 for the summer study. Sulfate analysis was by barium thorin titration and the resulting data calculated as SO_2. The data are provided in both English and Metric units. Data in parentheses are duplicate analyses, an internal quality control check.

PARTICULATE MASS AND PARTICULATE SULFATE DATA SUMMARY

Particulate mass loadings are summarized in Table 8, along with the results of the particulate sulfate analysis. The average particulate emission rate for the three heating boilers was 0.67 Kg/hr, with a range of 0.18 to 1.73 Kg/hr. The average emission rate for the two utility boilers was 11.53 Kg/hr, with a range of 4.78 to 20.40 Kg/hr. The heavy loading obtained in Test No. SBS-1 was the result of the boiler "kicking off" when the oil line was opened to retrieve an oil sample. The boiler was off for approximately three minutes.

The average particulate sulfate emission rate for the three heating boilers was 0.24 Kg/hr with a range of 0.06 to 0.39 Kg/hr. The two utility boilers averaged 2.63 Kg/hr with a range of 0.56 to 5.63 Kg/hr.

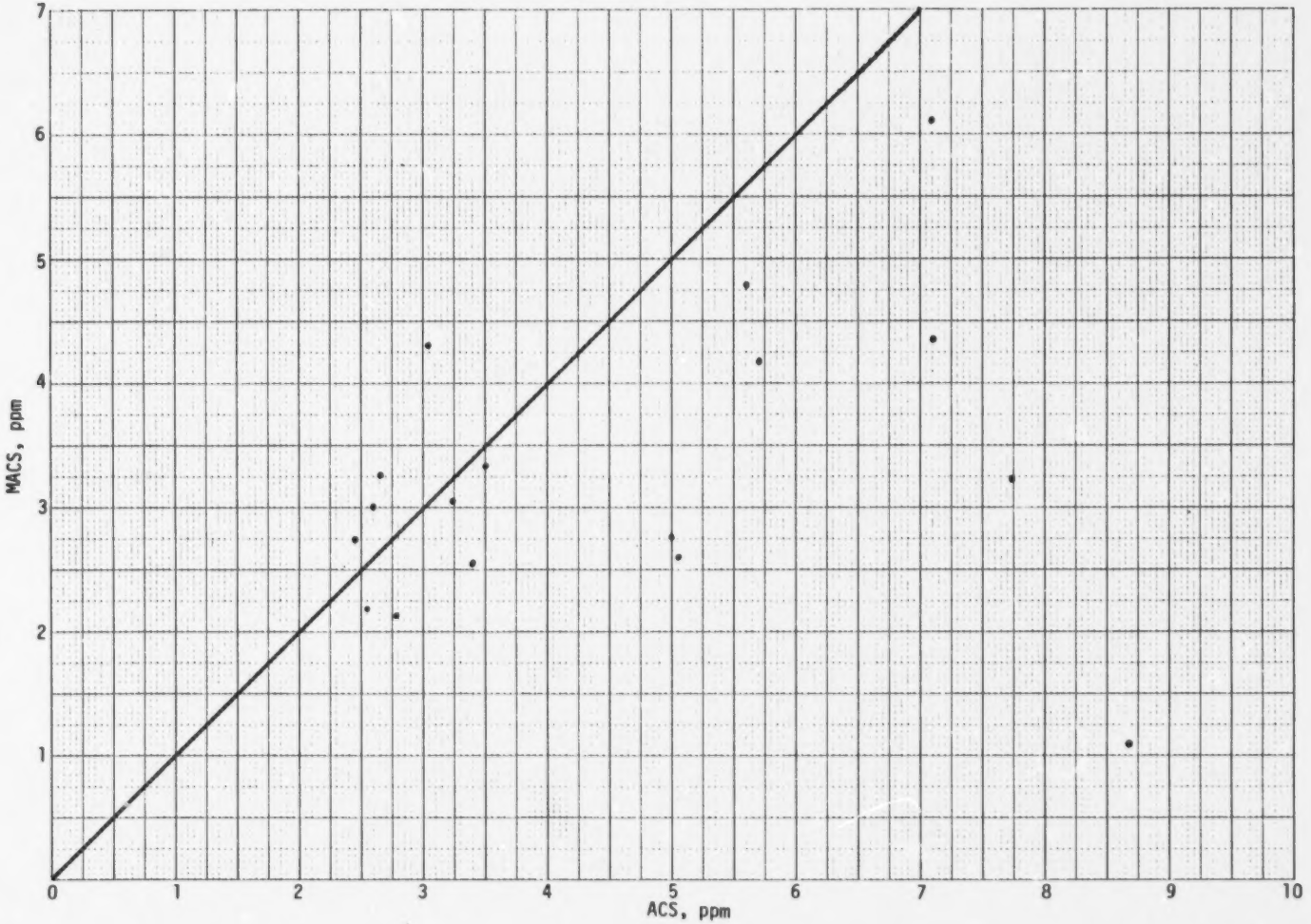

Figure 5. MACS versus ACS data - winter study.

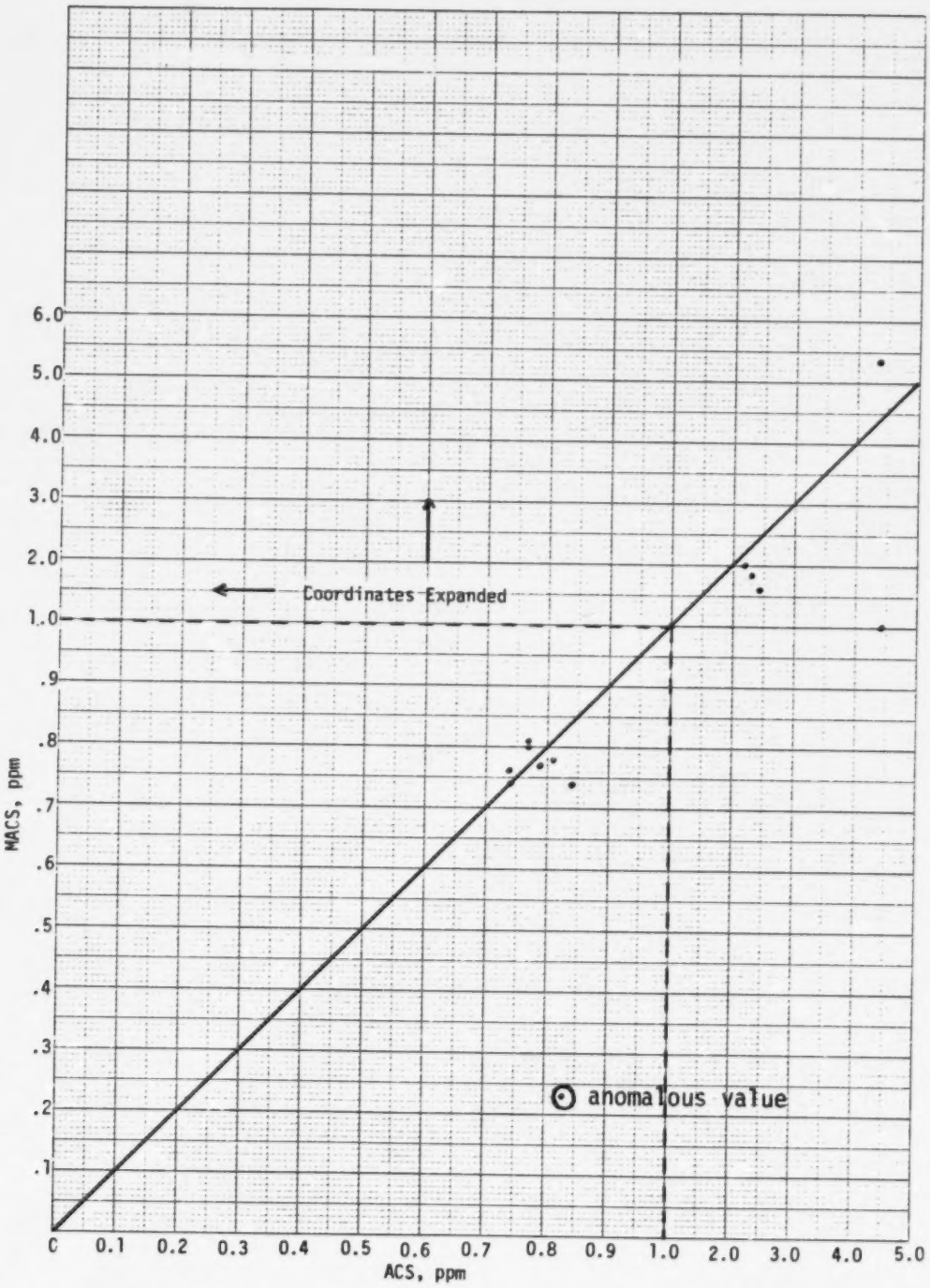

Figure 6. MACS versus ACS data - summer study.

TABLE 5. PARAMETER ESTIMATES FROM THE REGRESSION ANALYSES

	Alpha (α)	Beta (β)	Standard Deviation (σ)
Winter Study	1.57	0.41	0.89
Summer Study	0.21	0.67	0.97
Summer Study (Anomalous Point Removed)	-0.31	1.14	0.44

TABLE 6. SUMMARY OF MACS AND ACS SO_2 DATA - WINTER STUDY

Test No.	SO_4, mg	SO_2, mg	Sample Volume dscf (dscm)	SO_2 Conc., mg/dscf (mg/dscm)
GIR-MACS-1A-IMP	35.4 (34.0)*	23.14	2.461 (0.0697)	9.403 (331.994)
GIR-MACS-1B-IMP	28.2	19.07	2.449 (0.0694)	7.787 (274.784)
GIR-ACS-1-IMP	46.6	31.08	3.319 (0.0940)	9.364 (330.638)
GIR-MACS-2-IMP	24.0	16.01	2.324 (0.0658)	6.889 (243,313)
GIR-ACS-2-IMP	44.2 (43.6)	29.28	3.856 (0.1092)	7.593 (268.132)
GIR-MACS-3-IMP	28.3	18.87	2.978 (0.0843)	6.336 (223.843)
GIR-ACS-3-IMP	42.1	28.08	3.279 (0.0929)	8.564 (302.260)
GIR-MACS-4-IMP	39.2 (38.5)	25.91	2.937 (0.0832)	8.822 (311.418)
GIR-ACS-4-IMP	99.3 (100.7)	66.69	6.393 (0.1810)	10.432 (368.453)
GIR-MACS-5-IMP	30.1	20.07	2.533 (0.0717)	7.923 (279.916)
GIr-ACS-5-IMP	57.0	38.01	4.430 (0.1255)	8.580 (302.869)
GIR-MACS-6-IMP	44.6	29.74	2.911 (0.0824)	10.216 (360.922)
GIR-ACS-6-IMP	115.3 (115.3)	76.89	6.939 (0.1965)	11.081 (391.298)
PE-MACS-1-IMP	69.39	46.28	2.344 (0.0664)	19.744 (696.988)
PE-ACS-1-IMP	128.35	85.60	3.912 (0.1108)	21.881 (772.563)
PE-MACS-2-IMP	86.04	57.38	2.643 (0.0748)	21.710 (767.112)
PE-ACS-2-IMP	183.55 (182.59)	122.09	5.684 (0.1610)	21.480 (758.323)
PE-MACS-3-IMP	83.01 (82.03)	55.03	2.788 (0.0790)	19.738 (696.582)
PE-ACS-3-IMP	168.97	112.69	4.596 (0.1302)	24.579 (865.515)
PE-MACS-4-IMP	88.81	59.23	2.848 (0.0807)	20.797 (733.953)
PE-ACS-4-IMP	130.94	87.32	3.888 (0.1101)	22.459 (793.097)
PE-MACS-5-IMP	79.04	52.71	2.987 (0.0846)	17.646 (623.050)
PE-ACS-5-IMP	103.49	69.02	3.142 (0.0890)	21.967 (775.506)
PE-MACS-6-IMP	89.65	59.79	2.664 (0.0754)	22.444 (792.971)
PE-ACS-6-IMP	117.12	78.11	3.502 (0.0992)	22.304 (787.399)
MI-MACS-1-IMP	85.34	56.91	3.364 (0.0953)	16.917 (597.167)
MI-ACS-1-IMP	142.33	94.92	7.751 (0.2195)	12.246 (432.437)
MI-MACS-2-IMP	93.72	62.50	3.481 (0.0986)	17.955 (633.874)
MI-ACS-2-IMP	136.35	90.93	4.621 (0.1309)	19.678 (694.652)
MI-MACS-3-IMP	73.10 (72.10)	48.42	3.278 (0.0928)	14.771 (521.767)
MI-ACS-3-IMP	125.49	83.69	5.543 (0.1570)	15.098 (533.057)
MI-MACS-4-IMP	81.27	54.20	3.515 (0.0995)	15.420 (544.724)
MI-ACS-4-IMP	117.98	78.68	4.709 (0.1334)	16.708 (589.805)
MI-MACS-5-IMP	88.09	58.75	3.311 (0.0938)	17.744 (626.333)
MI-ACS-5-IMP	150.20	100.17	5.357 (0.1517)	18.699 (660.316)
MI-MACS-6-IMP	67.55	45.05	3.204 (0.0907)	14.061 (496.692)
MI-ACS-6-IMP	106.55	71.06	4.053 (0.1148)	17.533 (618.990)

*Data in parentheses are duplicate analyses.

TABLE 7. SUMMARY OF MACS AND ACS SO_2 DATA - SUMMER STUDY

Test No.	SO_4, mg	SO_2, mg	Sample Volume, dscf (dscm)	SO_2 Conc., mg/dscf (mg/dscm)
PES-MACS-IMP-1	93.0	62.02	3.340 (0.0946)	18.569 (655.603)
PES-ACS-IMP-1	114.4	76.29	3.819 (0.1081)	19.976 (705.735)
PES-MACS-IMP-2	100.9 (100.0*)	66.99	3.347 (0.0948)	20.015 (706.655)
PES-ACS-IMP-2	114.9	76.63	3.444 (0.0975)	22.250 (785.949)
PES-MACS-IMP-3	103.0	68.69	3.360 (0.0951)	20.443 (722.292)
PES-ACS-IMP-3	116.2 (115.7)	77.33	3.430 (0.0971)	22.545 (796.395)
PES-MACS-IMP-4	104.5	69.69	3.425 (0.0970)	20.374 (718.455)
PES-ACS-IMP-4	108.6	72.43	3.302 (0.0935)	21.935 (774.652)
PES-MACS-IMP-5	109.6	73.09	3.573 (0.1012)	20.456 (722.233)
PES-ACS-IMP-5	106.4	70.96	3.354 (0.0950)	21.157 (746.947)
SBS-MACS-IMP-1	24.9 (24.5)	16.47	3.110 (0.0881)	5.296 (186.947)
SBS-ACS-IMP-1	76.5	51.02	3.371 (0.0955)	15.135 (534.241)
SBS-MACS-IMP-2	71.0	47.35	3.102 (0.0878)	15.264 (539.294)
SBS-ACS-IMP-2	75.1	50.08	3.021 (0.0855)	16.577 (585.731)
SBS-MACS-IMP-3	69.1	46.08	3.295 (0.0933)	13.985 (493.891)
SBS-ACS-IMP-3	70.6	47.08	3.140 (0.0889)	14.994 (529.584)
SBS-MACS-IMP-4	67.7	45.15	3.137 (0.0888)	14.393 (508.446)
SBS-ACS-IMP-4	72.8 (73.6)	48.82	3.221 (0.0912)	15.157 (535.307)
SBS-MACS-IMP-5	77.8	51.88	3.009 (0.0852)	17.242 (608.920)
SBS-ACS-IMP-5	90.3	60.22	3.413 (0.0966)	17.644 (623.395)
SBS-MACS-IMP-6	71.0	47.35	3.007 (0.0851)	15.747 (556.404)
SBS-ACS-IMP-6	66.1	44.08	3.036 (0.0860)	14.191 (512.558)
SBS-MACS-IMP-7	68.4	45.62	3.178 (0.0900)	14.355 (506.889)
SBS-ACS-IMP-7	64.2	42.81	3.321 (0.0940)	12.891 (455.426)
SBS-MACS-IMP-8	70.6	47.08	3.262 (0.0924)	14.433 (509.524)
SBS-ACS-IMP-8	72.2	48.15	3.157 (0.0894)	15.252 (538.591)

*Data in parentheses are duplicate analysis.

TABLE 8. PARTICULATE SUMMARY - WINTER AND SUMMER STUDY

Test No.	Particulate Mass: Filter + FHR, mg	Particulate Mass: Concentration, mg/dscm	Particulate Mass: Emission Rate lb/hr	Particulate Mass: Emission Rate Kg/hr	Particulate Sulfate: Total H_2SO_4, mg	Particulate Sulfate: H_2SO_4 Concentration, mg/dscm	Particulate Sulfate: Emission Rate lb/hr	Particulate Sulfate: Emission Rate Kg/hr
				WINTER STUDY				
GIR-1	32.7	37.50	0.57	0.26	9.70	11.12	0.17	0.08
GIR-2	45.6	27.99	0.39	0.18	14.95	9.18	0.13	0.06
GIR-4	43.9	26.61	0.39	0.18	16.08	9.75	0.14	0.07
GIR-5	67.0	31.33	0.65	0.29	23.82	11.14	0.23	0.10
GIR-6	54.8	26.47	0.49	0.22	19.21	9.28	0.17	0.08
PE-1	191.7	88.24	14.89	6.75	16.01	7.37	1.24	0.56
PE-2	132.6	65.12	10.53	4.78	17.69	8.69	1.40	0.64
PE-3	186.7	151.67	19.40	8.80	14.17	11.51	1.47	0.67
MI-1[a]	113.8	72.89	1.45	0.66	36.46	23.36	0.47	0.21
MI-2[a]	78.9	57.21	0.56	0.25	55.48	40.23	0.39	0.18
MI-3[b]	156.2	95.50	2.91	1.32	107.21	65.53	1.99	0.90
				SUMMER STUDY				
PES-1	155.1	63.79	44.98	20.40	35.74	14.70	10.38	4.70
PES-2	91.3	41.26	29.27	13.28	30.22	13.66	9.71	4.40
PES-3	96.2	44.85	33.41	15.15	35.74	16.66	12.44	5.63
SBS-1	239.8	102.71	3.81	1.73	21.24	9.10	0.34	0.15
SBS-2	68.4	40.33	1.10	0.50	18.38	10.84	0.30	0.13
SBS-3	65.2	37.50	1.59	0.72	21.24	12.21	0.52	0.24
SBS-4	156.5	49.27	2.77	1.26	48.19	15.17	0.85	0.39

GIR, MI, and SBS are heating boilers; PE and PES are utility boilers.

(a) = with emulsion

(b) = without emulsion

PRIMARY SULFATE EMISSIONS AND PERCENT TOTAL SULFUR

Primary sulfate emissions (H_2SO_4, lbs/hr + part. sulfates, lbs/hr) and the percent total sulfur emitted as primary sulfate are summarized in Table 9. The data presented are averages of all tests conducted on each boiler. Percent total sulfur was derived in accordance with the following equation:

$$\% \text{ Sulfur} = \left\{ \frac{\left[(H_2SO_4,\ \text{lbs/hr})\left(\frac{32}{98}\right)\right] + \left[(\text{Part. Sulfate},\ \text{lbs/hr})\left(\frac{32}{96}\right)\right]}{\left[(H_2SO_4,\ \text{lbs/hr})\left(\frac{32}{98}\right)\right] + \left[(\text{Part. Sulfate},\ \text{lbs/hr})\left(\frac{32}{96}\right)\right] + \left[(SO_2,\ \text{lbs/hr})\left(\frac{32}{64}\right)\right]} \right\} \times 100$$

CARBON SPECIES SUMMARY

Total carbon results, including organic carbon and elemental carbon are summarized in Table 10. Carbonate carbon is not included in the table because none was detected in the summer study and only trace amounts on three filters from the winter study. In cases where carbonate was detected, it was subtracted from the measured organic carbon concentration. This was necessary because carbonate carbon is volatilized and measured in the organic carbon mode. The carbonate is included in total carbon calculations.

Total carbon emissions for the three heating boilers averaged 18.44 g/hr with a spread of 3.42 to 48.56 g/hr. The average total carbon emissions from the two utility boilers were 1471.21 g/hr with a spread of 74.86 to 4171.33 g/hr. Carbon emissions, in terms of mass of carbon per gallon of fuel oil burned, are also provided in Table 10. The full compliment of analytical results, including blanks and duplicate runs appears in Appendix B.

TABLE 9. PRIMARY SULFATE EMISSIONS AND PERCENT SULFUR

Boiler	Primary Sulfate Emission, lbs/gal	Sulfur Emitted as Primary Sulfate, %
GIR	0.0043	4.73
PE	0.0033	1.86
MI	0.0133	7.31
PES	0.0038	2.31
SBS	0.0026	1.91

TABLE 10. SUMMARY OF CARBON SPECIES* - WINTER AND SUMMER STUDY

Test No.	Qsd, dscm/hr	Organic Carbon			Elemental Carbon			Total Carbon			Total Carbon Emission Factor
		mg/dscm	g/hr	lb/hr	mg/dscm	g/hr	lb/hr	mg/dscm	g/hr	lb/hr	g/gal
WINTER STUDY											
GIR-1	6907.4	0.56	3.87	0.009	3.20	22.28	0.049	3.8	26.18	0.058	0.30
GIR-2	6350.6	0.33	2.08	0.005	1.70	10.74	0.024	2.0	12.83	0.028	0.14
GIR-4	6685.7	0.49	3.29	0.007	2.70	18.23	0.040	3.2	21.53	0.047	0.30
GIR-5	9361.9	0.26	2.40	0.005	2.80	26.23	0.058	3.1	28.65	0.063	0.33
GIR-6 (Duct A = 8 ft^2)	8365.1	0.28	2.32	0.005	5.10	42.67	0.094	5.4	45.00	0.099	0.63
PE-1	76544.1	1.50	115.45	0.255	34.70	2653.97	5.851	36.20	2769.37	6.105	2.53
PE-2	73320.0	1.50	106.47	0.235	18.70	1369.68	3.020	20.10	1475.93	3.254	1.30
PE-3 (Duct A = 91.67 ft^2)	58023.8	1.90	109.07	0.240	70.00	4061.90	8.955	71.90	4171.33	9.196	4.13
MI-1	9046.0	0.62	5.58	0.012	1.30	11.48	0.025	1.90	17.10	0.038	0.16
MI-2	4439.6	0.47	2.10	0.005	0.29	1.31	0.003	0.80	3.42	0.008	0.04
MI-3 (Duct A - 17.5 ft^2)	13809.3	0.37	5.08	0.011	0.16	2.23	0.005	0.50	7.32	0.016	0.06
SUMMER STUDY											
PES-1	320355.31	0.18	101.12	0.223	0.18	58.26	0.128	0.50	159.38	0.351	1.08
PES-2	322309.65	0.04	69.47	0.153	0.04	12.50	0.028	0.23	74.86	0.165	0.78
PES-3 (Duct A = 150 ft^2)	338451.12	0.16	122.46	0.270	0.16	53.92	0.119	0.52	176.38	0.389	1.42
SBS-1	16863.30	2.65	3.95	0.009	2.65	44.62	0.098	2.88	48.56	0.107	0.22
SBS-2	12446.61	1.18	1.79	0.004	1.18	14.75	0.033	1.33	16.54	0.036	0.09
SBS-3	19312.88	0.30	2.32	0.005	0.30	5.72	0.013	0.42	8.03	0.018	0.03
SBS-4 (Duct A = 27 ft^2)	25526.48	0.05	2.29	0.005	0.05	1.33	0.003	0.14	3.62	0.008	0.01

*No carbonate was found in the summer study and only trace amounts on three filters in the winter study.

SUMMARY OF TRACE ELEMENTS (PARTICULATE)

Trace element emission data obtained from the Method 5 filters are summarized in Table 11. An "x" associated with the element listed means that its concentration is less than the detection limits of the analytical method.

SUMMARY OF TRACE ELEMENTS (OIL)

Trace element concentrations obtained on the fuel samples are summarized in Table 12. The data reported are average concentrations derived from several samples obtained at each site. An "x" associated with the element listed means that its concentration is less than the detection limit of the analytical method.

TABLE 11. SUMMARY OF TRACE ELEMENTS ON METHOD 5 FILTERS, g/hr

Element	Winter Study											Summer Study						
	Site GIR					Site PE			Site MI			Site PES			Site SBS			
	No. 1	No. 2	No. 4	No. 5	No. 6	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 4
NA	X*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MG	0.23	0.22	0.18	0.25	0.12	4.57	4.34	3.28	0.72	0.33	0.86	104.60	97.91	89.34	16.05	12.99	16.39	17.18
AL	0.55	0.55	0.52	0.61	0.29	3.68	37.14	32.58	6.08	3.09	6.15	163.60	122.30	151.10	14.84	12.42	17.44	21.00
SI	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P	0.07	0.06	0.05	0.07	0.02	2.73	2.50	2.25	0.27	0.11	0.48	194.40	166.60	211.10	29.00	22.07	31.89	33.01
S	31.58	29.49	28.79	40.42	14.08	160.00	160.30	149.60	71.69	34.86	128.00	2019.00	1788.00	2075.00	102.00	79.51	145.80	178.20
CL	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0.49	0.04	X	X
K	0.09	0.04	0.07	0.10	0.06	2.60	2.48	1.94	0.55	0.26	0.51	42.74	32.57	39.45	1.83	1.31	1.84	2.23
CA	0.50	0.49	0.48	0.60	0.37	24.59	24.94	22.42	5.54	2.64	6.91	660.00	628.00	638.10	126.10	83.45	125.90	150.00
TI	0.04	X	0.05	0.05	0.03	3.48	3.58	3.05	0.48	0.23	0.42	27.51	20.75	25.18	2.58	1.84	2.75	3.60
V	2.00	2.06	1.96	2.50	1.81	49.38	48.23	40.72	4.74	2.29	7.57	365.20	247.10	296.30	16.86	11.52	17.41	22.46
CR	X	0.02	0.03	0.02	0.03	0.81	0.66	0.65	0.04	0.03	0.50	5.81	4.78	6.20	0.48	0.28	0.44	0.63
MN	X	0.02	0.01	0.02	0.01	0.81	0.72	0.67	0.08	0.03	0.08	7.32	5.54	5.33	0.53	0.37	0.55	0.78
FE	1.07	1.09	1.06	1.35	1.06	65.47	65.78	54.55	5.79	2.82	9.05	481.90	324.10	380.50	24.97	17.16	25.84	34.04
CO	0.16	0.17	0.17	0.21	0.16	6.15	6.05	4.89	0.29	0.14	0.79	27.10	16.79	19.73	1.67	1.14	1.71	2.33
NI	3.03	3.12	3.00	3.87	3.19	87.32	85.67	70.58	5.08	2.41	9.20	423.80	269.20	319.00	21.46	14.74	22.35	30.20
CU	0.09	0.11	0.09	0.11	0.09	1.13	1.06	0.87	0.20	0.09	0.92	18.53	12.49	1.14	1.35	0.92	1.32	1.82
ZN	0.08	0.11	0.10	0.11	0.10	5.18	5.01	3.68	0.47	0.20	0.73	206.40	144.70	172.10	18.08	12.56	18.69	25.67
AS	X	0.02	0.02	0.03	0.02	0.27	0.53	0.43	0.08	0.03	0.04	3.24	5.39	7.42	0.44	0.34	0.55	0.56
SE	0.03	X	X	X	X	X	X	0.02	0.14	X	X	X	0.58	1.15	0.08	0.08	0.13	0.09
BR	X	X	X	X	X	X	X	0.24	X	X	X	0.57	X	X	0.12	X	X	0.08
SR	X	0.04	0.05	0.08	0.06	1.96	1.74	1.85	0.27	0.14	0.43	10.63	8.91	11.23	0.67	0.48	0.74	1.01
MO	0.17	0.24	0.16	0.24	0.18	2.28	1.93	2.56	0.28	0.15	1.44	52.26	39.95	51.32	0.77	0.45	0.74	0.98
CD	X	X	X	X	X	0.03	0.04	0.02	X	X	0.01	1.01	0.84	0.80	0.27	0.20	0.25	0.26
SN	0.01	0.01	0.02	0.01	0.01	0.46	0.46	0.42	0.09	0.04	0.11	12.00	11.19	11.43	2.25	1.47	2.23	2.66
SB	0.02	0.02	0.01	0.02	0.01	0.28	0.27	0.22	0.03	0.01	0.12	21.44	15.87	17.36	0.31	0.21	0.32	0.37
BA	0.06	0.09	0.06	0.07	0.05	1.73	1.70	1.46	0.28	0.13	0.73	43.42	44.07	48.41	12.94	8.90	13.17	16.86
W	X	X	X	X	X	X	X	X	X	X	X	1.90	2.20	2.70	0.14	0.12	0.15	0.21
PB	0.16	0.02	0.02	X	X	2.59	1.96	1.57	0.26	0.09	0.44	262.20	244.70	285.00	19.18	13.46	19.69	26.80

X = Element less than detection limit.

TABLE 12. FUEL OIL ANALYSIS, ppm

Element	Site GIR, No. 4 Oil	Site PE, No. 6 Oil	Site MI, No. 6 Oil	Site PES, No. 6 Oil	Site SBS, No. 6 Oil
P	2.32	2.40	40.28	13.04	21.12
S	2823.22 (2925.00*)	5115.71 (5400.00)	4512.05 (4700.00)	5311.23 (4950.00)	5679.72 (5400.00)
CL	6.25	22.75	28.81	60.69	54.04
CA	2.15	5.77	9.74	40.89	111.31
TI	X**	1.11	1.19	2.10	2.88
V	9.26 (7.78)	17.39 (13.20)	14.46 (12.67)	16.94 (18.67)	17.47 (18.00)
NI	16.48	24.27	X	23.14	24.10

*Nos. in parentheses are duplicate analyses by BCL, V by ICAP, S by XRF.

**X = Element less than detection limit.

QUALITY ASSURANCE

A Quality Assurance Plan for this study, prepared according to interim guidelines and specifications given in QAMS-005/80 (December 29, 1980), was submitted to EPA on July 13, 1982. Although the plan was submitted at the conclusion of the winter study (Task 6), it was rigidly adhered to for both studies, WA-6 and WA-12.

The Quality Assurance Project Officer for the study was Sandra M. Anderson. In this capacity Mrs. Anderson was responsible for surveillance and formal reporting on all quality assurance program activities to ensure that data are collected which meet the accuracy, precision, completeness, representativeness, and comparability objectives set forth in the QA document.

Due to time and cost factors of this study an external system audit of field sampling operations was not scheduled.

REFERENCES

1. J. L. Cheney and J. B. Homolya, "Workshop Proceedings on Primary Sulfate Emissions from Combustion Sources", EPA-600/9-78-020a, p. 53, U.S. Environmental Protection Agency, Research Triangle Park, N.C., 1978.

2. Johnson, R. L., Shah, J. J., Cary, R. A., Huntzicker, J. J., "Automated Thermal Optical Method for the Analysis of Carbonaceous Aerosol", in Atmospheric Aerosol: Source/Air Quality Relationships, ACS Symposium Series No. 167, Published by American Chemical Society, 1981, pp. 223-233.

APPENDIX A

BOILER OPERATIONAL DATA

Load
Fuel Consumption
Fyrite Measurements

BOILER GIR - OPERATIONAL DATA

March 23, 1982

	Time	Oil, gal/hr
	07:00 - 08:00	85
	08:00 - 09:00	92
	09:00 - 10:00	82
	10:00 - 11:00	61
12:43	11:00 - 12:00	80
ACS MACS-1	12:00 - 13:00	87
13:39	13:00 - 14:00	92
14:17	14:00 - 15:00	90
M5-1	15:00 - 16:00	85
15:17		

March 24, 1982

	Time	Oil, gal/hr
08:20	07:00 - 08:00	76
M5-2	08:00 - 09:00	76
10:20	09:00 - 10:00	103
	10:00 - 11:00	80
	11:00 - 12:00	84
	12:00 - 13:00	95
	13:00 - 14:00	79
	14:00 - 15:00	84
15:47	15:00 - 16:00	73
	16:00 - 17:00	67
M5-4	17:00 - 18:00	75
17:47		

March 25, 1982

	Time	Oil, gal/hr
	07:00 - 08:00	112
08:15	08:00 - 09:00	82
	09:00 - 10:00	92
M5-5	10:00 - 11:00	82
10:15	11:00 - 12:00	81
11:36	12:00 - 13:00	82
ACS MACS-2	13:00 - 14:00	93
12:11	14:00 - 15:00	79
13:07	15:00 - 16:00	71
ACS MACS-3		
13:42		
14:10		
M5-6		
16:10		

March 26, 1982

	Time	Oil, gal/hr
	07:00 - 08:00	104
	08:00 - 09:00	
	09:00 - 10:00	Boiler
	10:00 - 11:00	Down
	11:00 - 12:00	for
	12:00 - 13:00	Repairs
	13:00 - 14:00	128
13:48	14:00 - 15:00	109
ACS MACS-4	15:00 - 16:00	99
14:58	16:00 - 17:00	90
16:07	17:00 - 18:00	128
ACS MACS-5	18:00 - 19:00	131
16:52		
18:05		
ACS MACS-6		
19:05		

Steam gauge pressure was 105 psi for all runs.

BOILER PE - OPERATION DATA

March 29, 1982

		Time	Steam, 1000 lb/hr	Oil, gal/hr
	11:30	11:10 - 12:10	105	1096
M5-1		12:10 - 13:10	105	1092
	13:30	13:10 - 14:10	104	1415
	14:49	14:10 - 15:10	105	1125
M5-2		15:10 - 16:10	106	1131
	16:49	16:10 - 17:00	74	1148

March 30, 1982

		08:30 - 09:30	90	891
ACS MACS-1	08:47	09:30 - 10:30	88	831
	09:32	10:30 - 11:30	80	831
ACS MACS-2	11:18	11:30 - 12:30	80	831
	12:00	12:30 - 13:30	80	966
ACS MACS-3	13:26	13:30 - 14:30	80	966
	14:16	14:30 - 15:30	80	966
ACS MACS-4	15:17	15:30 - 16:30	80	865
	16:59			

March 31, 1982

ACS MACS-5	08:05	08:00 - 09:00	95	903
	08:40	09:00 - 10:00	92	903
ACS MACS-6	09:40	10:00 - 11:00	90	901
	10:40	11:00 - 12:00	92	887
	12:48	12:00 - 13:00	92	885
M5-3		13:00 - 14:00	92	915
	14:48	14:00 - 15:00	91	1107

BOILER MI - OPERATIONAL DATA

April 2, 1982

		Time	Oil, gal/hr
	10:10	09:15 - 10:15	100.8
M5-1		10:15 - 11:15	108.0
		11:15 - 12:15	
	12:10	12:15 - 13:15	104.0
		13:45 - 14:45	96.1
	13:58	14:45 - 15:45	87.7
M5-2		15:45 - 16:45	68.0
	16:58	16:45 - 17:00	17.3

April 5, 1982

ACS MACS-1	08:19	08:20 - 09:20	104.3
	09:14	09:20 - 10:20	107.8
		10:20 - 11:20	108.9
ACS MACS-2	10:23	11:20 - 12:20	99.5
	11:08		
ACS MACS-3	12:10	12:20 - 13:20	122.4
	13:00		
ACS MACS-4	13:57	13:20 - 14:20	86.1
	14:36	14:20 - 15:20	103.9

April 6, 1982

ACS MACS-5	09:02	09:30 - 10:30	116.3
	09:57	10:30 - 11:30	116.2
ACS MACS-6	10:54	11:30 - 12:30	103.1
	11:34	12:30 - 13:30	110.2
M5-3	13:00	13:30 - 14:30	116.2
	15:00		

BOILER PES - OPERATIONAL DATA

August 4, 1982

		Time	Steam, 1000 lb/hr	Oil, bbl/hr
		00:00 - 01:00	400	103.7
		01:00 - 02:00	400	103.7
		02:00 - 03:00	400	103.7
		03:00 - 04:00	400	103.7
		04:00 - 05:00	400	103.7
		05:00 - 06:00	400	103.7
		06:00 - 07:00	510	132.2
		07:00 - 08:00	550	142.5
		08:00 - 09:00	575	149.0
		09:00 - 10:00	575	149.0
		10:00 - 11:00	560	145.1
	11:04	11:00 - 12:00	560	145.1
M5-1		12:00 - 13:00	575	149.9
	13:04	13:00 - 14:00	560	145.1
		14:00 - 15:00	560	145.1
		15:00 - 16:00	525	136.0
	16:24	16:00 - 17:00	500	129.6
ACS MACS-1		17:00 - 18:00	450	116.6
	17:05			
		18:00 - 19:00	460	119.2
		19:00 - 20:00	460	119.2
		20:00 - 21:00	440	114.0
		21:00 - 22:00	425	110.1
		22:00 - 23:00	420	108.8
		23:00 - 24:00	410	106.2
			11515	

Oil consumption 00:00 to 24:00 = 2984 bbl

Oil by direct line from supplier
Usage reported on 24-hour basis

Calculations: $\text{bbl/hr} = \frac{\text{steam/hr}}{\text{steam/24-hr}}$ (oil/24 hrs)

BOILER PES - OPERATIONAL DATA (Continued)

August 5, 1982

	Time	Steam, 1000 lb/hr	Oil, bbl/hr
	00:00 - 01:00	400	70.9
	01:00 - 02:00	400	70.9
	02:00 - 03:00	390	69.2
	03:00 - 04:00	400	70.9
	04:00 - 05:00	400	70.9
	05:00 - 06:00	430	76.3
	06:00 - 07:00	470	83.3
	07:00 - 08:00	520	92.2
	08:00 - 09:00	560	99.3
ACS MACS-2 08:21	09:00 - 10:00	560	99.3
09:01	10:00 - 11:00	550	97.5
ACS MACS-3 10:41	11:00 - 12:00	550	97.5
11:16			
	12:00 - 13:00	540	95.8
M5-2 12:21	13:00 - 14:00	545	96.6
14:21	14:00 - 15:00	540	95.8
	15:00 - 16:00	510	90.4
	16:00 - 17:00	490	86.9
	17:00 - 18:00	480	85.1
	18:00 - 19:00	470	83.3
	19:00 - 20:00	470	83.3
	20:00 - 21:00	440	78.0
	21:00 - 22:00	420	74.5
	22:00 - 23:00	400	70.9
	23:00 - 24:00	400	70.9
		11335	

Oil consumption 00:00 to 24:00 = 2010 bbl

BOILER PES - OPERATIONAL DATA (Continued)

August 6, 1982

	Time	Steam, 1000 lb/hr	Oil, bbl/hr
	00:00 - 01:00	400	90.1
	01:00 - 02:00	400	90.1
	02:00 - 03:00	400	90.1
	03:00 - 04:00	400	90.1
	04:00 - 05:00	400	90.1
	05:00 - 06:00	440	99.2
	06:00 - 07:00	465	104.8
	07:00 - 08:00	550	123.9
ACS	08:15		
	08:00 - 09:00	560	126.2
MACS-4	08:55		
	09:00 - 10:00	560	126.2
ACS	10:01		
	10:00 - 11:00	510	114.9
MACS-5	10:36		
	11:00 - 12:00	540	121.7
	11:39		
M5-3			
	12:00 - 13:00	560	126.2
	13:39		
	13:00 - 14:00	555	125.1
	14:00 - 15:00	540	121.7
	15:00 - 16:00	525	118.3
	16:00 - 17:00	490	110.4
	17:00 - 18:00	450	101.4
	18:00 - 19:00	450	101.4
	19:00 - 20:00	460	103.7
	20:00 - 21:00	445	100.3
	21:00 - 22:00	430	96.9
	22:00 - 23:00	420	94.6
	23:00 - 24:00	410	92.4
		11360	

Oil consumption 00:00 to 24:00 = 2560 bbl

BOILER SBS - OPERATIONAL DATA

August 9, 1982

		Time	Steam, 1000 lb/hr	Oil, gal/hr
		09:00 - 10:00	24.5	210
ACS-1	09:43	10:00 - 11:00	20.3	176
MACS-1	10:18	11:00 - 12:00	25.8	219
ACS-2	11:06	12:00 - 13:00	26.6	225
MACS-2	12:12	13:00 - 14:00	27.7	230
M5-1	13:28	14:00 - 15:00	26.1	214
	15:28			

August 10, 1982

		07:30 - 08:30	21.8	189
ACS-3	08:01	08:30 - 09:30	22.3	192
MACS-3	08:41	09:30 - 10:30	21.7	187
ACS-4	09:12	10:30 - 11:30	21.2	183
MACS-4	09:52	11:30 - 12:30	21.4	182
M5-2	10:54	12:30 - 13:30	22.2	189
	12:54			

August 11, 1982

ACS-5	07:55	07:30 - 08:30	31.5	265
MACS-5	08:30	08:30 - 09:30	28.8	244
ACS-6	09:12	09:30 - 10:30	29.7	247
MACS-6	09:48	10:30 - 11:30	28.1	233
M5-3	11:02	11:30 - 12:30	28.8	244
	13:02	12:30 - 14:05	40.7	342

August 12, 1982

ACS-7	07:54	07:30 - 08:30	27.0	240
MACS-7	08:29	08:30 - 09:30	33.6	289
ACS-8	09:05	09:30 - 10:30	33.1	280
MACS-8	09:40	10:30 - 11:30	30.7	260
M5-4	10:29	11:30 - 12:40	38.1	322
	12:29			

AVERAGE FYRITE MEASUREMENTS, %

Test No.	CO_2	O_2	N_2*
GIR-1	8.0	13.0	75.0
GIR-2	10.4	11.0	78.6
GIR-4	7.0	10.7	82.3
GIR-5	7.3	10.7	82.0
GIR-6	7.7	11.5	80.8
PE-1	12.7	7.8	79.5
PE-2	7.2	12.8	80.0
PE-3	13.7	7.6	78.7
MI-1	10.7	8.6	80.7
MI-2	10.1	9.0	80.9
MI-3	9.1	9.8	81.1
		Summer Study	
PES-1	14.4	5.3	80.3
PES-2	14.2	4.1	81.7
PES-3	13.2	4.1	82.7
SBS-1	10.3	9.1	80.6
SBS-2	10.1	11.5	78.4
SBS-3	10.2	11.4	78.4
SBS-4	9.8	12.0	78.2

* Obtained by difference [100 - (% CO_2 + % O_2)]

APPENDIX B

CARBON ANALYSIS BY AUTOMATED THERMAL-OPTICAL METHOD

The following points concerning the carbon analyses results should be noted:

1. At least one blank filter was run on each analysis day. These are listed at the top of the page. When more than one blank was run on a given day, the blank values are reported as "BLNK. AVE" or "AVE. BLNK".

2. The appropriate blank values have been subtracted from the organic, elemental, and carbonate carbon results.

3. The highlighted values are the averages of all valid runs and are expressed as $\mu g\ C/cm^2$.

4. The carbonate values are also given as $\mu g\ C/cm^2$. In cases where carbonate carbon was present, the carbonate carbon concentration was subtracted from the measured organic carbon concentration. This was necessary because carbonate carbon is volatilized and measured in the organic carbon mode. The carbonate subtraction was performed only on the average results.

5. For the individual analyses, the uncertainties are derived from the propagated uncertainties associated with each of the analytical steps. The uncertainties of the averages are simply the average of the uncertainties from the individual analyses and do not represent the distribution of replicate values.

6. In most instances agreement among the replicates was reasonable. In those cases where a result appears to be an outlier, inhomogeneous deposition on the filter is the likely explanation.

7. Speciation between organic and elemental carbon was in some cases difficult because of a non-carbonaceous, optically absorbing material present on the filters.

CARBON ANALYSIS

Filter ID	Organic Carbon, µg C/cm^2	Elemental Carbon, µg C/cm^2	Total Carbon, µg C/cm^2	CO_3 Carbon, µg C/cm^2
POFB-M5-3	0.43	1.09	1.52	
Blank Ave.	0.81	0.24	1.06	
Ave. Blank	0.74	0.85	1.59	
POFB-M5-3	0.43	0.04	0.47	
POFB-M5-1	1.11	1.40	2.52	
POFB-M5-2	0.79	1.45	2.24	0.60
PE-0329-M5-1-PF	76.43 ± 11.49	1819.67 ± 272.95	1896.10 ± 273.19	
PE-0329-M5-1-PF	68.48 ± 10.31	1481.45 ± 222.22	1549.93 ± 222.46	
Average	71.8 ± 10.9	1650.6 ± 247.6	1722.4 ± 247.8	0.64
MI-042-M5-1-PF	24.44 ± 3.75	42.34 ± 6.37	66.77 ± 7.39	
MI-042-M5-1-PF	17.67 ± 3.32	44.55 ± 7.12	62.22 ± 7.07	
Average	21.1 ± 3.5	43.4 ± 6.7	64.5 ± 7.2	
PE-0329-M5-2-PF	61.40 ± 9.24	842.92 ± 126.44	904.33 ± 126.78	
PE-0329-M5-2-PF	70.71 ± 10.73	824.28 ± 123.64	894.98 ± 124.11	
Average	64.8 ± 10.0	833.6 ± 125.0	898.4 ± 125.4	1.32
PE-0331-M5-3-PF	50.08 ± 7.65	1809.45 ± 271.42	1859.53 ± 271.52	
PE-0331-M5-3-PF	51.41 ± 7.85	1966.79 ± 295.02	2018.20 ± 295.12	
Average	50.7 ± 7.8	1888.1 ± 283.2	1938.9 ± 283.2	
MI-042-M5-2-PF	15.82 ± 2.50	10.20 ± 1.59	26.01 ± 2.96	
MI-042-M5-2-PF	12.74 ± 5.05	7.68 ± 4.99	20.43 ± 1.90	
Average	14.3 ± 3.8	8.9 ± 3.3	23.2 ± 2.4	
MI-046-M5-3-PF	18.38 ± 2.86	2.60 ± 0.62	20.98 ± 2.93	
MI-046-M5-3-PF	16.19 ± 2.55	7.68 ± 1.24	23.88 ± 2.84	
MI-046-M5-3-PF	15.04 ± 2.39	6.40 ± 1.06	21.44 ± 2.61	
MI-046-M5-3-PF	10.27 ± 1.36	6.54 ± 1.10	16.80 ± 1.75	
Average	13.2 ± 2.3	5.8 ± 1.0	19.0 ± 2.5	1.80
GIR-0323-M5-1-PF	7.25 ± 1.34	57.18 ± 8.59	64.43 ± 8.69	
GIR-0323-M5-1-PF	14.07 ± 4.22	66.09 ± 10.67	80.16 ± 10.05	
Average	10.7 ± 2.8	61.6 ± 9.6	72.3 ± 9.4	
GIR-0324-M5-2-PF	12.70 ± 2.06	67.19 ± 10.09	79.89 ± 10.30	
GIR-0324-M5-2-PF	10.64 ± 1.78	53.59 ± 8.05	64.23 ± 8.25	
Average	11.7 ± 1.9	60.4 ± 9.1	72.1 ± 9.3	
GIR-0324-M5-4-PF	17.03 ± 2.67	136.02 ± 20.41	153.04 ± 20.58	
GIR-0324-M5-4-PF	10.75 ± 1.37	79.25 ± 11.91	89.99 ± 11.96	
GIR-0324-M5-4-PF	21.91 ± 2.46	85.42 ± 12.82	107.33 ± 13.06	
GIR-0324-M5-4-PF	21.42 ± 2.65	93.52 ± 14.04	114.95 ± 14.28	
Average	17.8 ± 2.3	98.6 ± 14.8	116.3 ± 15.0	

CARBON ANALYSIS (Continued)

Filter ID	Organic Carbon, µg C/cm^2	Elemental Carbon, µg C/cm^2	Total Carbon, µg C/cm^2	CO_3 Carbon, µg C/cm^2
GIR-0325-M5-5-PF	15.60 ± 2.47	148.96 ± 22.35	164.55 ± 22.48	
GIR-0325-M5-5-PF	11.34 ± 3.07	121.03 ± 18.35	132.36 ± 18.23	
GIR-0325-M5-5-PF	8.99 ± 1.23	123.83 ± 18.58	132.82 ± 18.62	
Average	12.0 ± 2.3	131.3 ± 19.8	143.2 ± 19.8	
GIR-0325-M5-6-PF	13.02 ± 2.10	254.88 ± 38.23	267.89 ± 38.29	
GIR-0325-M5-6-PF	12.14 ± 3.39	207.83 ± 31.32	219.97 ± 31.22	
Average	12.6 ± 2.7	231.4 ± 34.8	243.9 ± 34.8	
Blank	2.28	0.98	3.26	
Blank	2.29	0.75	3.04	
Blank	2.26	1.21	3.48	
PES-084-M5-1	18.59 ± 2.83	11.37 ± 1.78	29.96 ± 3.33	
PES-084-M5-1	15.05 ± 2.47	8.00 ± 1.37	23.05 ± 2.75	
Average	16.82 ± 2.65	9.69 ± 1.58	26.51 ± 3.04	
PES-085-M5-2	10.05 ± 1.84	1.88 ± 0.57	11.92 ± 1.91	
PES-085-M5-2	10.85 ± 1.91		10.59 ± 1.90	
Average	10.45 ± 1.88	1.88 ± 0.57	11.26 ± 1.905	
PES-086-M5-3	16.84 ± 2.81	8.16 ± 1.32	25.00 ± 3.10	
PES-086-M5-3	17.18 ± 2.73	6.82 ± 1.21	24.00 ± 2.93	
Average	17.01 ± 2.77	7.49 ± 1.26	24.50 ± 3.015	
SBS-089-M5-1	10.60 ± 5.47	130.95 ± 20.32	141.55 ± 19.72	
SBS-089-M5-1	13.33 ± 3.08	139.74 ± 21.11	153.07 ± 21.05	
Average	11.97 ± 4.28	135.35 ± 20.72	147.31 ± 20.39	
SBS-0810-M5-2	5.64 ± 1.14	45.76 ± 6.88	51.40 ± 6.97	
SBS-0810-M5-2	5.05 ± 1.30	42.30 ± 6.40	47.35 ± 6.46	
Average	5.35 ± 1.22	44.03 ± 6.64	49.38 ± 6.72	
SBS-0811-M5-3	4.49 ± 1.15	10.89 ± 1.78	15.38 ± 1.98	
SBS-0811-M5-3	4.65 ± 1.08	11.66 ± 1.83	16.31 ± 2.10	
Average	4.57 ± 1.12	11.28 ± 1.81	15.85 ± 2.04	
SBS-0812-M5-4	6.03 ± 1.23	3.23 ± 0.87	9.26 ± 1.28	
SBS-0812-M5-4	6.44 ± 1.24	4.01 ± 0.91	10.45 ± 1.38	
Average	6.24 ± 1.24	3.62 ± 0.89	9.86 ± 1.33	

No carbonate carbon was found.

Note: Because of the non-carbonaceaous brown material on the filters, accurate speciation between organic and elemental carbon was not possible. Thus, the numbers cited above must be considered as upper limits for elemental carbon and lower limits for organic carbon.

SUMMARY OF TOTAL CARBON DATA - WINTER STUDY

Test No.	Vm (std), dscm	Qsd, dscm/hr	Total C, µg/dscm	Total C, g/hr
GIR-0323-M5-1	0.871	6907.4	3790	26.18
GIR-0324-M5-2	1.628	6350.6	2020	12.83
GIR-0324-M5-4	1.649	6685.7	3220	21.53
GIR-0325-M5-5	2.137	9361.9	3060	28.65
GIR-0325-M5-6	2.069	8365.1	5380	45.00
(Duct Area = 8 ft^2)				
PE-0329-M5-1	2.171	76544.1	36180	2769.37
PE-0329-M5-2	2.035	73320.0	20130	1475.93
PE-0331-M5-3	1.230	58023.8	71890	4171.33
(Duct Area = 91.67 ft^2)				
MI-042-M5-1	1.560	9046.0	1890	17.10
MI-042-M5-2	1.378	4439.6	770	3.42
MI-046-M5-3	1.635	13809.3	530	7.32
(Duct Area = 17.5 ft^2)				

Working Area of Filter = 45.604 cm^2

SUMMARY OF ELEMENTAL CARBON DATA - WINTER STUDY

Test No.	Vm (std), dscm	Qsd, dscm/hr	Elem. C, µg/dscm	Elem. C, g/hr
GIR-0323-M5-1	0.871	6907.4	3230	22.28
GIR-0324-M5-2	1.628	6350.6	1690	10.74
GIR-0324-M5-4	1.649	6685.7	2730	18.23
GIR-0325-M5-5	2.137	9361.9	2800	26.23
GIR-0325-M5-6	2.069	8365.1	5100	42.67
(Duct Area = 8 ft^2)				
PE-0329-M5-1	2.171	76544.1	34670	2653.97
PE-0329-M5-2	2.035	73320.0	18680	1369.68
PE-0331-M5-3	1.230	58023.8	70000	4061.90
(Duct Area = 91.67 ft^2)				
MI-042-M5-1	1.560	9046.0	1270	11.48
MI-042-M5-2	1.378	4439.6	290	1.31
MI-046-M5-3	1.635	13809.3	160	2.23
(Duct Area = 17.5 ft^2)				

Working Area of Filter = 45.604 cm^2

SUMMARY OF ORGANIC CARBON DATA - WINTER STUDY

Test No.	Vm (std), dscm	Qsd, dscm/hr	Organic C, µg/dscm	Organic C, g/hr
GIR-0323-M5-1	0.871	6907.4	560.23	3.87
GIR-0324-M5-2	1.628	6350.6	327.74	2.08
GIR-0324-M5-4	1.649	6685.7	492.27	3.29
GIR-0325-M5-5	2.137	9361.9	256.08	2.40
GIr-0325-M5-6	2.069	8365.1	277.73	2.32
(Duct Area = 8 ft^2)				
PE-0329-M5-1	2.171	76544.1	1508.23	115.45
PE-0329-M5-2	2.035	73320.0	1452.16	106.47
PE-0331-M5-3	1.230	58023.8	1879.77	109.07
(Duct Area = 91.67 ft^2)				
MI-042-M5-1	1.560	9046.0	616.82	5.58
MI-042-M5-2	1.378	4439.6	473.25	2.10
MI-046-M5-3	1.635	13809.3	368.18	5.08
(Duct Area = 17.5 ft^2)				

Working Area of Filter = 45.604 cm^2

SUMMARY OF CO_3 CARBON DATA - WINTER STUDY

Test No.	Vm (std), dscm	Qsd, dscm/hr	CO_3 C, µg/dscm	CO_3 C, g/hr
GIR-0323-M5-1	0.871	6907.4	-	-
GIR-0324-M5-2	1.628	6350.6	-	-
GIR-0324-M5-4	1.649	6685.7	-	-
GIR-0325-M5-5	2.137	9361.9	-	-
GIR-0325-M5-6	2.069	8365.1	-	-
(Duct Area = 8 ft^2)				
PE-0329-M5-1	2.171	76544.1	13.44	1.03
PE-0329-M5-2	2.035	73320.0	29.58	2.17
PE-0331-M5-3	1.230	58023.8	-	-
(Duct Area = 91.67 ft^2)				
MI-042-M5-1	1.560	9046.0	-	-
MI-042-M5-2	1.378	4439.6	-	-
MI-046-M5-3	1.635	13809.3	50.21	0.69
(Duct Area = 17.5 ft^2)				

Working Area of Filter = 45.604 cm^2

SUMMARY OF TOTAL CARBON DATA - SUMMER STUDY

Test No.	Vm (std), dscm (dscf)	Qsd, dscm/hr	Total C, µg/dscm	Total C, g/hr
PES-084-M5-1	2.430 (85.86)	320355.31	497.515	159.382
PES-085-M5-2	2.211 (78.14)	322309.65	232.248	74.856
PES-086-M5-3	2.144 (75.75)	338451.12	521.128	176.376
(Duct Area = 150 ft^2)				
SBS-089-M5-1	2.333 (82.45)	16863.30	2879.522	48.558
SBS-0810-M5-2	1.695 (59.89)	12446.61	1328.570	16.536
SBS-0811-M5-3	1.738 (61.40)	19312.88	415.894	8.032
SBS-0812-M5-4	3.175 (112.18)	25526.48	141.624	3.615
(Duct Area = 27 ft^2)				

Working Area of Filter = 45.604 cm^2

SUMMARY OF ELEMENTAL CARBON DATA - SUMMER STUDY

Test No.	Vm (std), dscm (dscf)	Qsd, dscm/hr	Elem. C, µg/dscm	Elem. C, g/hr
PES-084-M5-1	2.430 (85.86)	320355.31	181.853	58.258
PES-085-M5-2	2.211 (78.14)	322309.65	38.777	12.498
PES-086-M5-3	2.144 (75.75)	338451.12	159.316	53.921
(Duct Area = 150 ft^2)				
SBS-089-M5-1	2.333 (82.45)	16863.30	2645.736	44.616
SBS-0810-M5-2	1.695 (59.89)	12446.61	1184.628	14.745
SBS-0811-M5-3	1.738 (61.40)	19312.88	295.980	5.716
SBS-0812-M5-4	3.175 (112.18)	25526.48	51.996	1.327
(Duct Area = 27 ft^2)				

Working Area of Filter = 45.604 cm^2

SUMMARY OF ORGANIC CARBON DATA - SUMMER STUDY

Test No.	Vm (std), dscm (dscf)	Qsd, dscm/hr	Organic C, µg/dscm	Organic C, g/hr
PES-084-M5-1	2.430 (85.86)	320355.31	315.662	101.124
PES-085-M5-2	2.211 (78.14)	322309.65	215.541	69.471
PES-086-M5-3	2.144 (75.75)	338451.12	361.812	122.456
(Duct Area = 150 ft^2)				
SBS-089-M5-1	2.333 (82.45)	16863.30	233.982	3.946
SBS-0810-M5-2	1.695 (59.89)	12446.61	143.942	1.792
SBS-0811-M5-3	1.738 (61.40)	19312.88	119.914	2.316
SBS-0812-M5-4	3.175 (112.18)	25526.48	89.628	2.288
(Duct Area = 27 ft^2)				

Working Area of Filter = 45.604 cm^2